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LEWIS AEROPROPULSION TECHNOLOGY: REMEMBERING THE PAST AND CHALLENGING THE FUTURE

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It was on January 23, 1941, less than two years after the first flight of a jet-propelled aircraft, that George Lewis, Director of Aeronautical Research for NACA, broke ground in Cleveland for the NACA Aircraft Engine Research Laboratory (AERL), which was to bear his name after his death in 1948. Originally envisioned as a laboratory for fundamental research on piston engines, the new NACA laboratory never actually fulfilled this role. From the first test in 1942 until the war's end in 1945, primary emphasis was on trouble-shooting to solve the problems of engines in production for the war effort. By the end of the war, the transition from piston to jet propulsion was well underway, and with it went the direction of the laboratory's program.

In this presentation, we will revisit some of our major accomplishments over the past fifty years and pick up the gauntlet to meet the challenges of the future. From piston engines through environmentally acceptable high-speed propulsion systems, efforts have included and will continue to include discipline, component, and engine activities along with provision of unique facilities to carry out our programs.

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Remembering the Past

- Historical facilities
- Component technologies
- Environmental acceptability
- Energy efficiency

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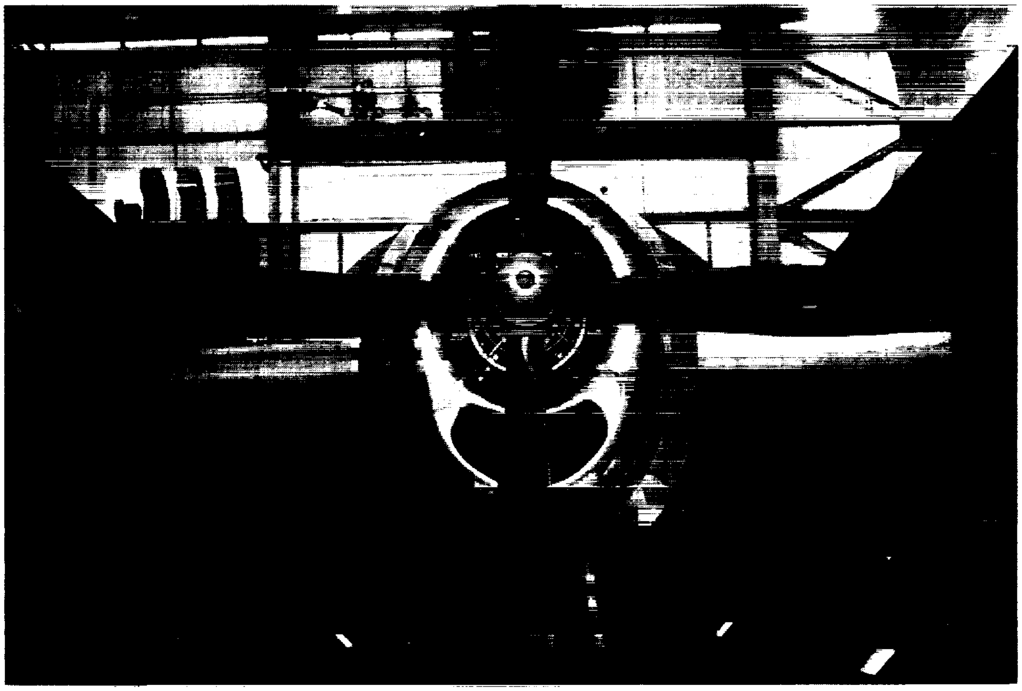
After addressing key problems (turbocharging, carburetion, cooling) plaguing the advanced piston engines being produced for the war, research focus shifted to gas turbine engines for turbojet, turbofan, and turboprop propulsion systems. Advances were made in the understanding and state of the critical discipline technologies (materials, internal fluid mechanics, structures, instrumentation, controls), the capability and efficiency of components (propellers, compressors, turbines, combustors, inlets, nozzles), and the fuel efficiency and environmental acceptability (noise, emissions) of engines. Let us now recall some of the more notable aeropropulsion technology achievements of the Lewis Research Center over the past half century.

Piston Engines and the Altitude Wind Tunnel



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After much debate, the full-scale Altitude Wind Tunnel (AWT) was included as one of the first facilities built at AERL. The concern was that the AWT would be used for engine development, which should be the domain of the engine companies. Fortunately, the tunnel was built, as it was given credit by some for shortening the war.

Although the AWT was designed for piston engine testing, the first tests were conducted in February 1944 on the secret I-16 turbojet engine developed by General Electric from the Whittle prototype. The first official tests in AWT were with the Wright R-3350 piston engine urgently needed for the B-29 bomber. This engine, which had been rushed into production, had many problems, the foremost of which was random poor fuel distribution causing unpredictable cylinder overheating. This was corrected by use of fuel injection instead of a carburetor. This and other fixes developed in the Lewis AWT contributed to the B-29's, including the Enola Gay's, being able to fly above the enemy's altitude capability while performing its missions.

Icing Research Tunnel

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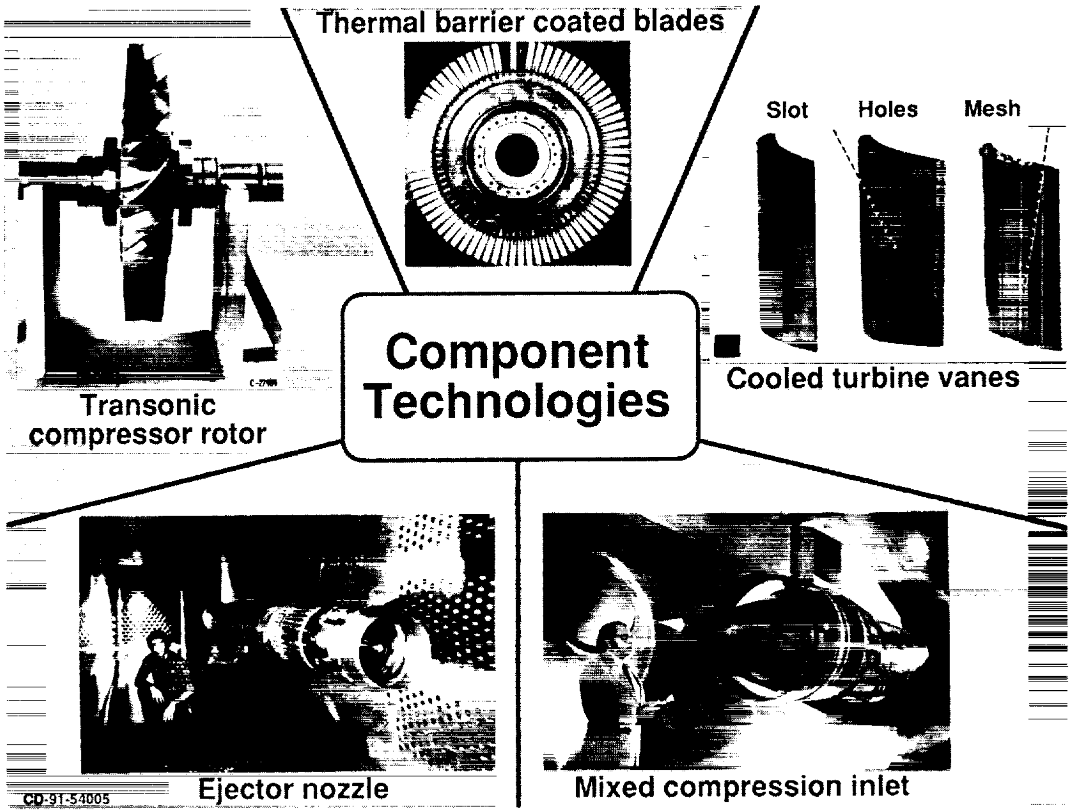
Responding to a critical need expressed by the Army Air Force and aircraft manufacturers, the NACA initiated research on aircraft icing and directed that an Icing Research Tunnel (IRT) be added to the AWT under construction. Developing this unique capability required unusual ingenuity to solve critical technical problems. The first icing test was run on June 9, 1944. Today, the IRT remains the world's largest refrigerated icing tunnel.

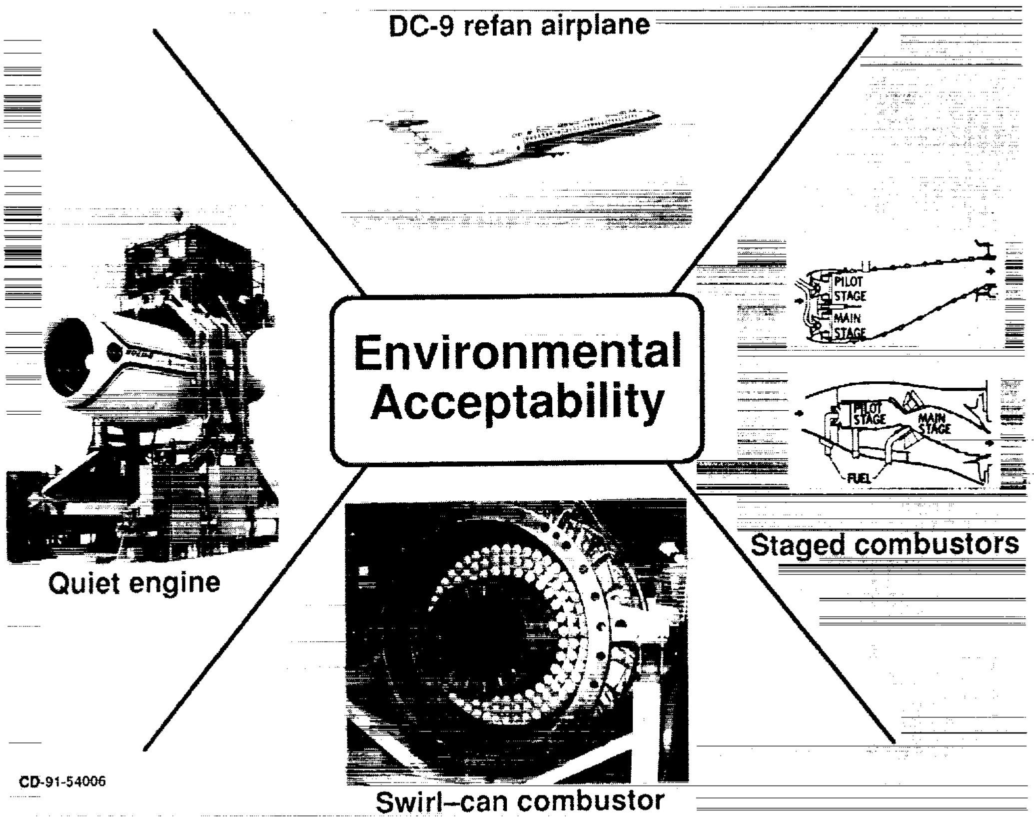
The heat exchanger design was revolutionary; it can maintain a spatially uniform air temperature over a very large range of airspeed and temperature, even when subjected to severe icing. Another major innovation was the spray system. In 1943, no one knew just how small natural cloud droplets were or how to measure them, let alone how to duplicate them. By the mid-1940's, the nature of the droplets had been defined and by early 1950, the spray system was capable of producing droplets small enough to reproduce realistic icing patterns.

Between 1950 and 1958, the IRT was used for extensive testing of aircraft components. The anti-icing technology used on today's commercial transports was largely developed in the IRT. Over the next 20 years, with icing problems seemingly solved, the tunnel was used very little. In 1978, NASA re-instituted an icing research program to address the needs for new aircraft designs. After a major renovation in 1986, the IRT is again in heavy demand from government and industry. In 1987, the American Society of Mechanical Engineers (ASME) designated the Lewis Research Center's Icing Research Tunnel an International Historic Mechanical Engineering Landmark for its leading role in making aviation safer for everyone.



Much research has been devoted to understanding, extending, and documenting the capabilities and operating limits of engine components and associated disciplines. Operational increases in flight speed and in engine temperature and pressure ratio came about only after the components were able to efficiently accommodate them. Early axial-flow compressors were limited to stage pressure ratios of 1.1 to 1.2 because of the design limitation to subsonic flow. Blade shapes capable of transonic operation were developed to produce a stage pressure ratio approaching 1.4, thus resulting in substantial stage reduction. Turbine inlet temperature capability has increased substantially as a result of high-temperature turbine materials and turbine cooling. Research in the areas of alloy development, failure mechanisms, and protective coatings, including thermal barriers, has contributed to numerous heat-resistant, long-life turbine disk and blade materials. Advances in casting technology enabled the development of advanced cooling concepts. A systematic program of cascade and turbine tests documented the effects of number, location, size, and angle of cooling holes, thus providing an extensive data base for the design of aerodynamically efficient cooled blading.

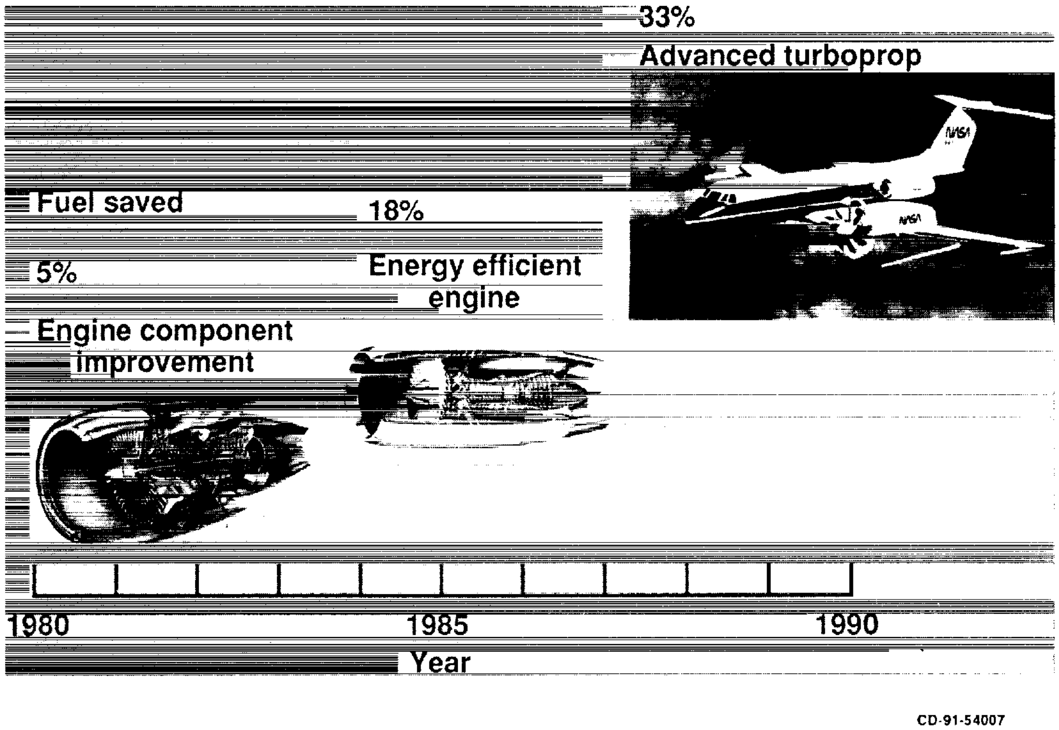
Extensive studies of characteristics such as efficiency, stability, and distortion for a wide variety of supersonic inlets have produced an inlet design and control data base that has been used for the design of inlets for many military aircraft. Many of these inlets were developed using the Lewis tunnels. Exhaust nozzle testing in both isolated and installed configurations has been aimed primarily at noise reduction and at variable geometry for good performance at both subsonic and supersonic flight. This data has also been used extensively by industry.



The phenomenal growth of air traffic in the early 1960's intensified an already growing concern about aircraft noise and emissions and led to programs addressing these environmental issues. The Quiet Engine was an experimental engine whose primary objective was to provide a full-size demonstration of the effectiveness of noise reduction techniques. General Electric designed and built the engine, while Boeing provided the nacelle. Engine tests at NASA Lewis demonstrated that the Quiet Engine technologies, compared to the current 707 and DC-8 aircraft engines, could provide about 20 EPNdB noise reduction without fan acoustic treatment and nearly 30 EPNdB with an acoustic nacelle. The Refan Program was a demonstration of using noise abatement technologies to quiet the narrow-body fleet by retrofit. On the basis of Pratt & Whitney and NASA engine tests (JT8D), Boeing ground tests (727 nacelles), and Douglas flight tests (DC-9), it was shown that 5 to 10 EPNdB takeoff and landing noise reduction and greater than 60 percent reduction in area exposed to 90 dB and higher noise levels were achievable.

Lewis has played a major role in the evolution of low-pollutant combustor technology. The swirl-can combustor concept, which operates leaner than a conventional combustor, demonstrated a twofold reduction in nitrogen oxide emissions. The Experimental Clean Combustor Program, in which Pratt & Whitney and General Electric participated, developed the technology for staged combustion concepts that provided a twofold reduction in nitrogen oxides at takeoff and about a tenfold reduction in carbon monoxide and hydrocarbon emissions at idle. A staged combustor will be used in the next generation of civil high-bypass engines, which is scheduled to enter service in the next few years.

Energy Efficient Propulsion Technology

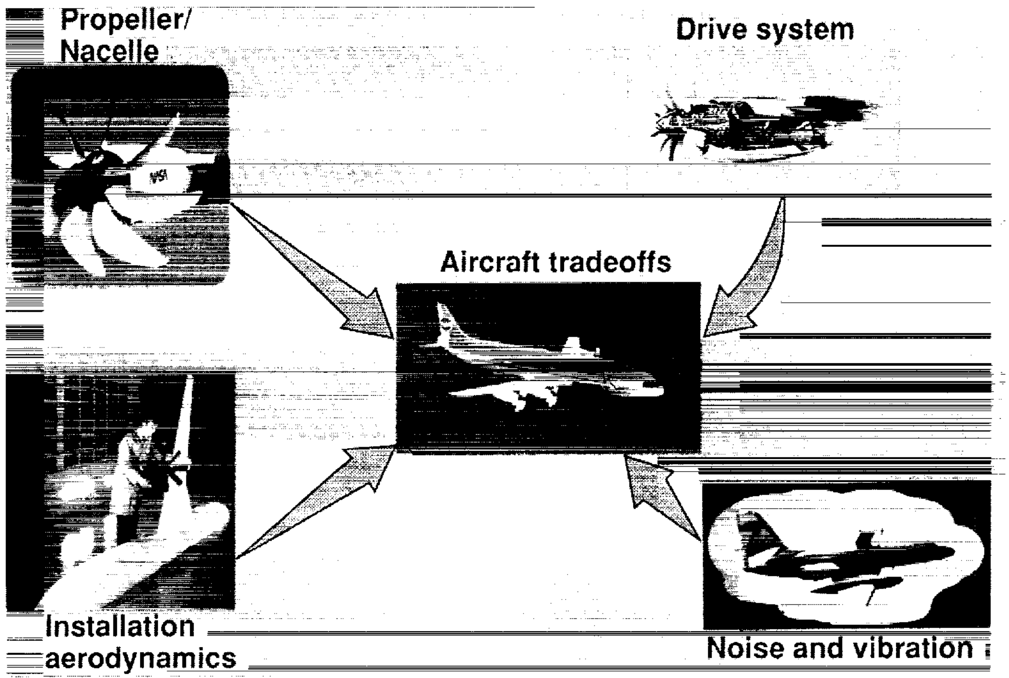


In January 1975, the U.S. Senate requested NASA to establish an advanced technology program for aircraft fuel conservation. The NASA Aircraft Energy Efficiency Program was thus initiated, with three of its six elements focusing on propulsion: two addressing turbofan engines and one addressing turboprops. The turbofan elements were Engine Component Improvement (ECI) and Energy Efficient Engine (EEE). General Electric and Pratt & Whitney participated in both of these programs.

The ECI project was expected to provide near term fuel savings of 5 percent for the existing commercial fleet. The performance improvement was to come from improved component aerodynamics, reduced leakages, and reduced cooling. Concepts implemented on the basis of fuel savings potential and favorable benefit/cost ratio resulted in total fuel savings meeting the 5 percent goal. NASA was reimbursed for program costs based on commercial sales of the upgraded engines incorporating ECI technologies.

The objective of the EEE project was to provide a technology base for a new generation of fuel efficient turbofan engines with specific fuel consumption at least 12 percent below that of then-current high-bypass engines. This program was based on "clean-sheet" design engines. Advanced technologies were evaluated in sub-scale and full-scale rigs and then incorporated into both core and integrated core/low spool engines for final evaluation. Fuel savings were achieved through use of an advanced cycle, improved components, and a mixer. If all the EEE technologies were applied to an optimized new engine, the fuel savings benefit would be about 18 percent. Substantial portions of the fuel savings of current technology engines can be attributed to EEE technology developments.

Advanced Turboprop Enabling Technology



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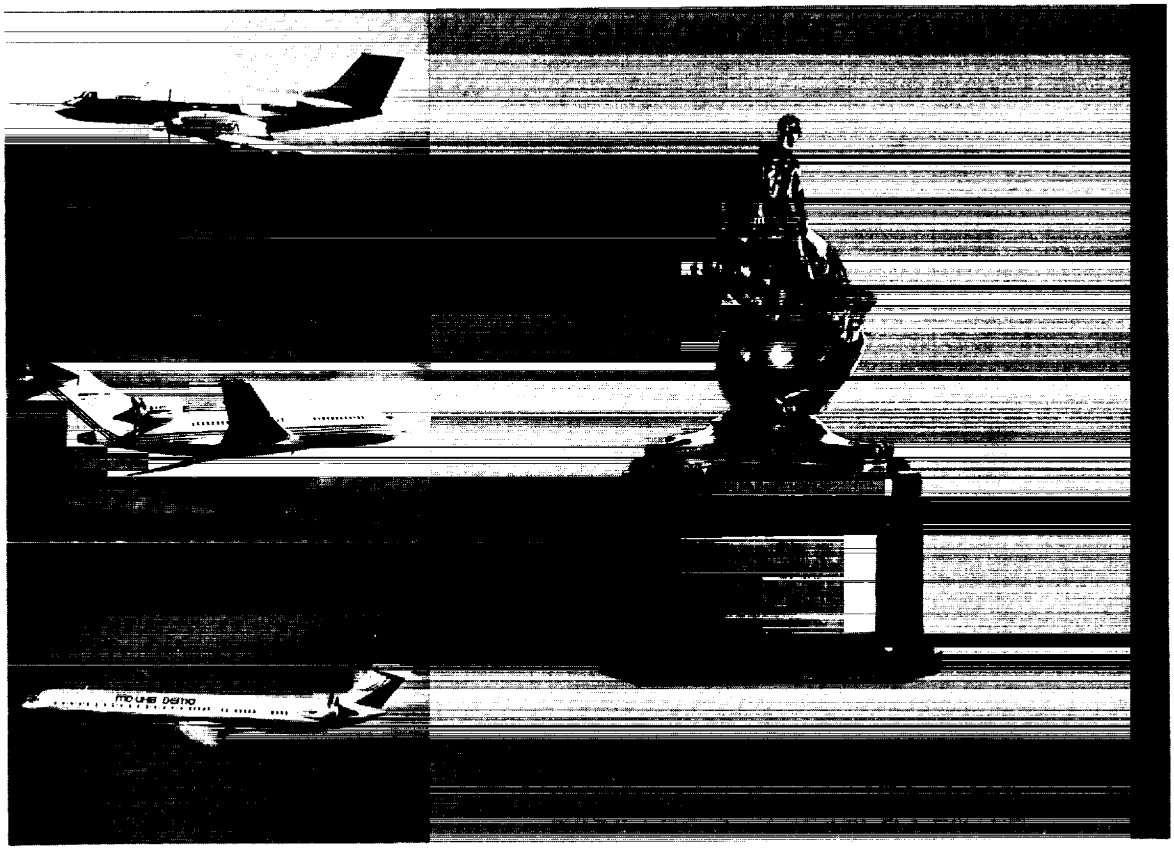
The third propulsion element of the Aircraft Energy Efficiency Program was the Advanced Turboprop, which provided the highest potential fuel savings - about 30 to 35 percent relative to then-current high-bypass turbofan engines. To address this most challenging concept, the approach followed a logic path that started with analyses and proceeded to design codes and designs based on scale-model tests. Large-scale systems were then designed, ground tested, and ultimately flight tested. All key system elements were considered, and geared single-rotation as well as direct-drive and geared counterrotation concepts were included.

Achievement of high propeller efficiency and low noise combined with structural integrity were key to program success. These requirements were addressed and demonstrated early in the program through a combination of scale-model tests and code development. Installing the turboprop on a wing could reduce the efficiencies of both the wing and the engine, thus severely limiting any fuel efficiency gains. Model tests were used to study installation effects in Ames and Langley wind tunnels. Because of power levels and number of blades, neither the drive system's gearbox nor its blade pitch-change mechanism could be of conventional design. Lewis along with several major engine companies had to develop these technologies. There were major concerns about effects of turboprop noise and vibration on both interior and community environments. Under Lewis direction, Dryden took responsibility for model-source-noise flight testing and Langley for aircraft interior environment analysis and noise attention. With the enabling technology developed, large-scale system design and testing could be undertaken.

Advanced Turboprop Proof of Concept



Beginning in August 1986, the advanced turboprop propulsion concept was proven by flight programs using large-scale hardware. The NASA/General Electric/Boeing flight test and the General Electric/McDonnell Douglas flight test used the Unducted Fan as a proof-of-concept demonstrator for the gearless counterrotating concept and provided in-flight performance and acoustic data. The NASA/Lockheed-Georgia Propfan Test Assessment flight test verified the structural integrity and acoustic characteristics of the single-rotation Large-Scale Advanced Propfan built by Hamilton Standard. Encouraged by these results, Pratt & Whitney/Allison built a geared counterrotating engine, based on design data acquired in Lewis-funded Allison gearbox and Hamilton Standard/United Technologies Research Center model tests, and flight tested it on a McDonnell Douglas aircraft.

In recognition of the success of this effort, the NASA Lewis Research Center and the NASA/industry advanced turboprop team were awarded the 1987 Collier Trophy, which is awarded yearly for the greatest achievement in aeronautics or astronautics. Studies, model tests, and flight tests have shown that turboprops with thin, swept, highly loaded blades can operate at high speeds (Mach 0.65 to 0.85) and reduce fuel consumption 25 to 30 percent relative to advanced turbofans and 40 to 50 percent relative to today's aircraft.

Challenging the Future

- Vision/thrusts
- Focused programs
- Basic- and multi-discipline technologies
- Facilities

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In the future, we at NASA Lewis Research Center will continue to develop and assist the application of advanced technologies required for high performance propulsion systems for civilian and military aircraft. We will accomplish this by conducting focused research and technology efforts related to the prime propulsion needs of subsonic, supersonic cruise, rotorcraft/general aviation, high-performance military, and hypersonic/TAV aircraft. In addition, we will give continuing emphasis to the critical basic disciplines of internal fluid mechanics, instrumentation and controls, materials, and structures, and to efforts aimed at the complex interactions among multiple disciplines. Further, we must assure that our facilities meet our research needs.

Our Vision

To be the Nation's pathfinder in innovative aerospace propulsion R&T

Commits us to:

- **Technology advances**
- **World-class computational and experimental facilities**
- **A challenging working environment**
- **Strong collaborative relationships with external partners**

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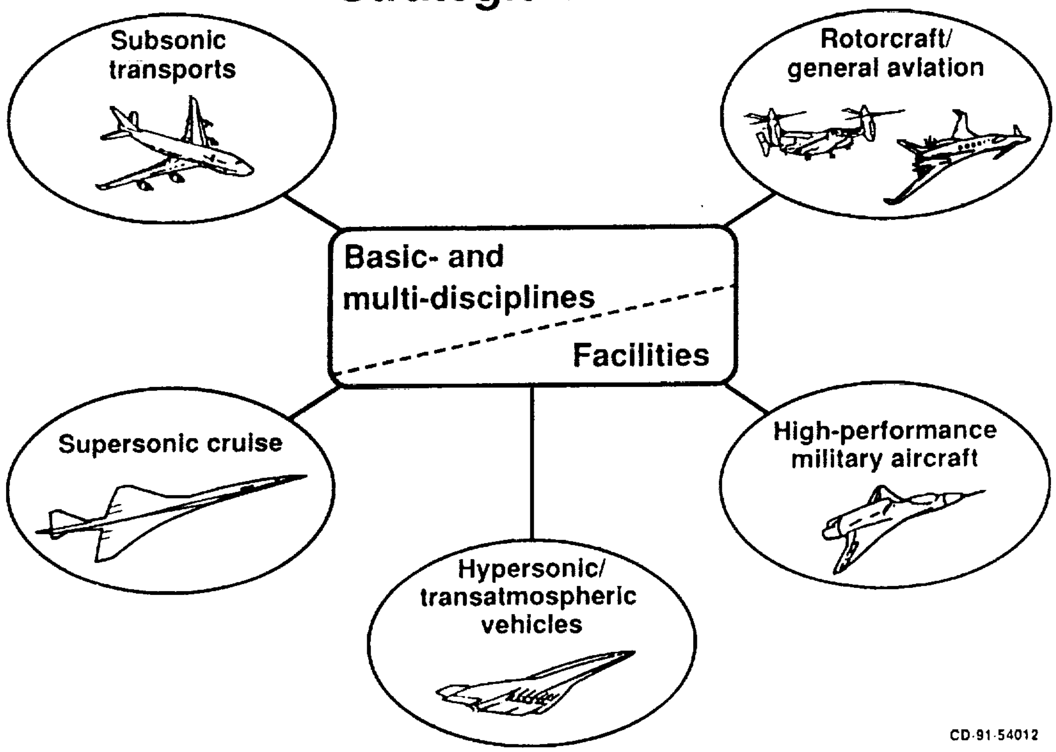
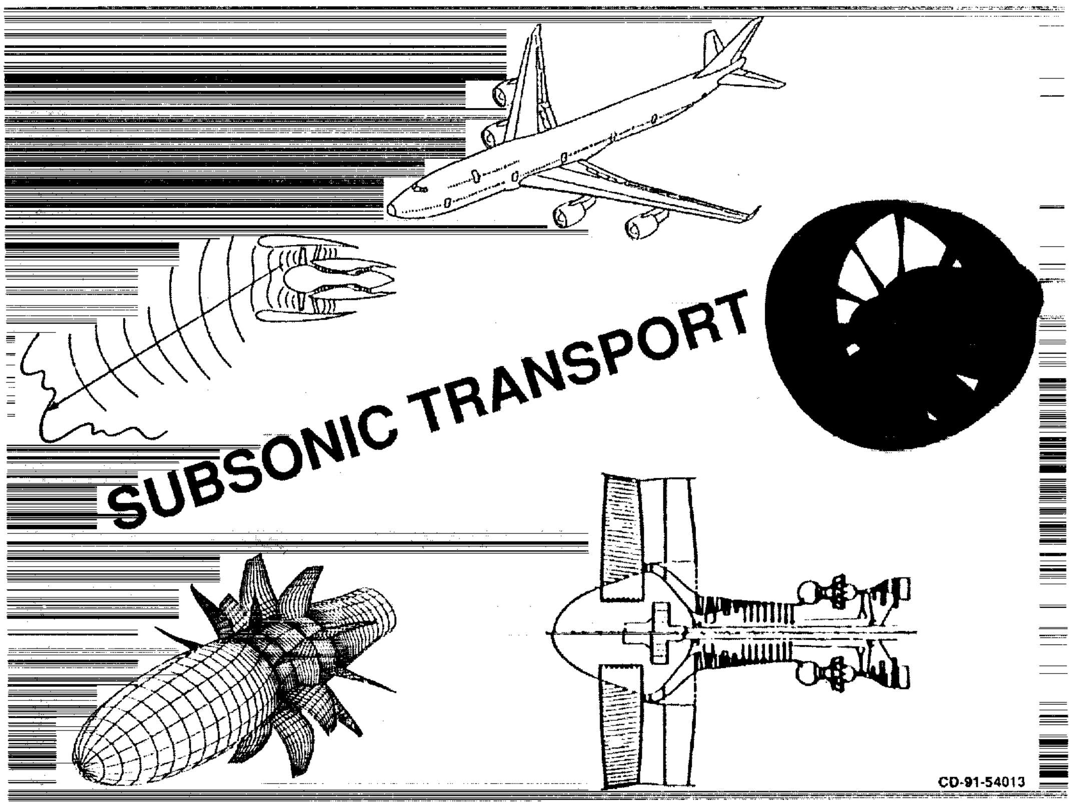
The Lewis Research Center aeropropulsion vision, presented above, commits us to (1) conduct high-payoff innovative research to provide leading-edge propulsion technology advances, (2) develop, maintain, and effectively utilize world-class computational and experimental facilities, (3) provide an exciting action-oriented working environment which attracts, develops, and retains outstanding scientists and engineers, (4) promote strong collaborative relationships with industry, universities, and other government agencies, and (5) fulfill our programmatic commitments at the same time.

Strategic Thrusts

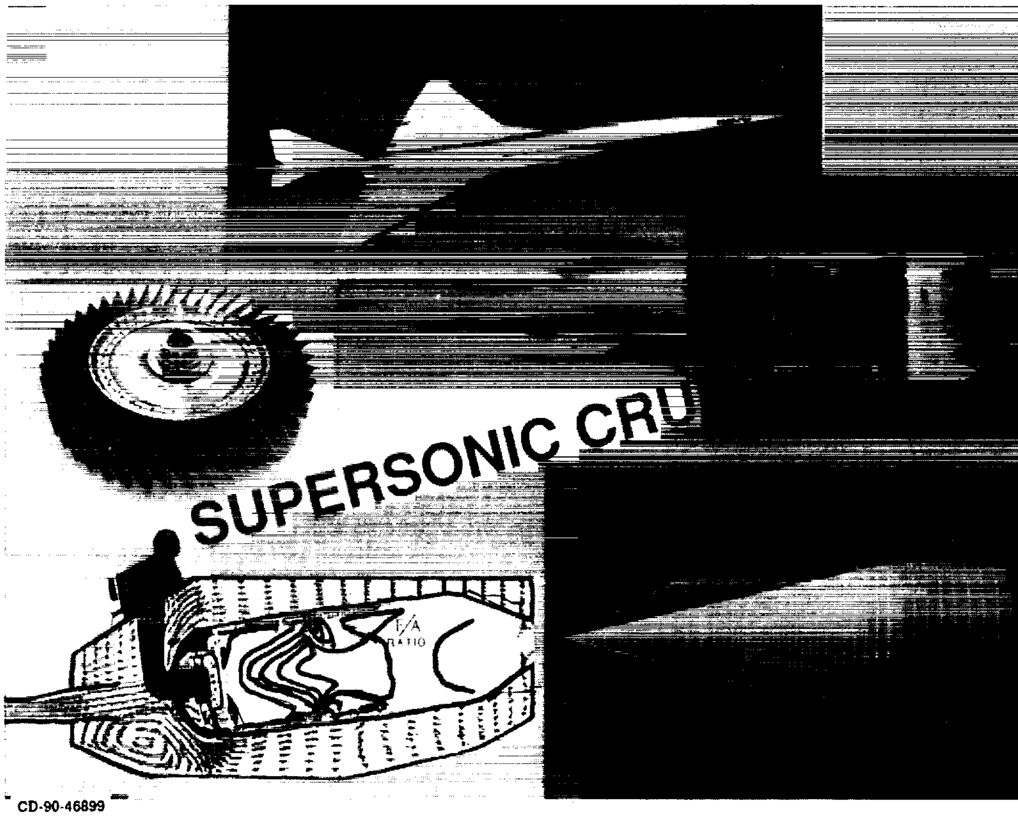


The NASA aeronautics strategic thrusts provide the focus for the specific elements of the aeropropulsion program. We implement our propulsion technology efforts through five vehicle-focused elements (subsonic transports, supersonic cruise, hypersonic/transatmospheric vehicles, high-performance military aircraft, and small-engine technologies for rotorcraft/general aviation aircraft) plus some generic technology elements involving both basic-disciplinary and multi-disciplinary research. About two-thirds of our resources are directed at the five vehicle-focused elements, and the remaining one-third is invested in our generic research and our aeropropulsion facilities that are essential to all of our efforts.



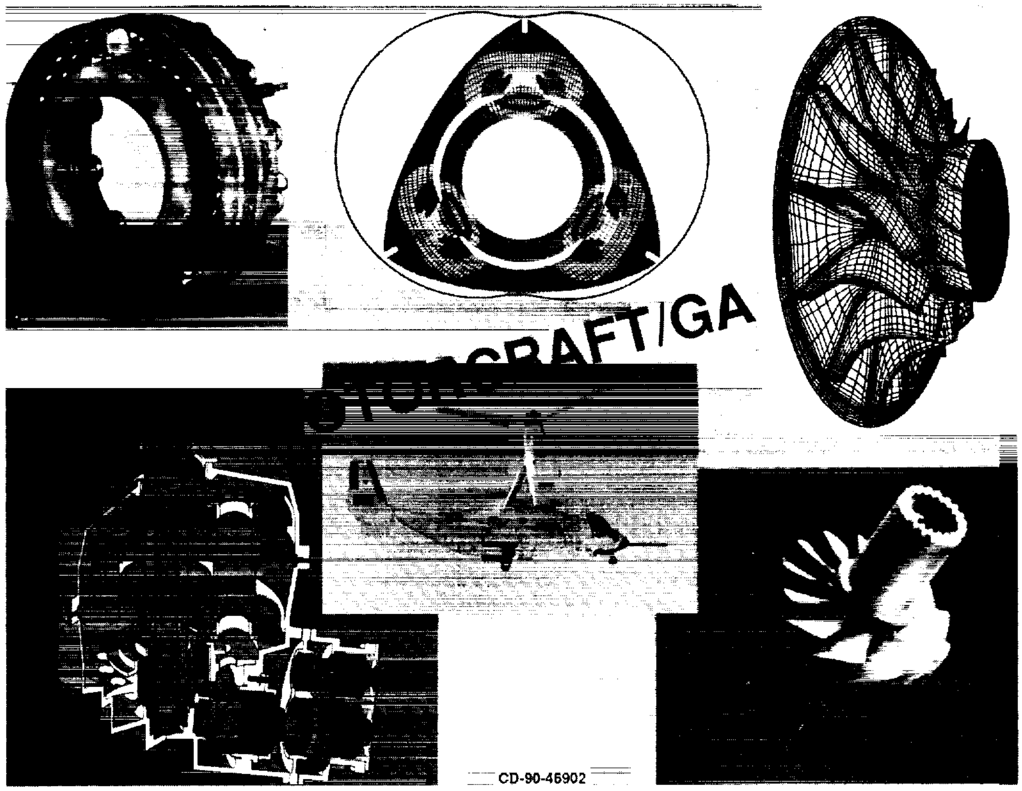
The goal of this program is to achieve revolutionary advances in efficiency and environmental acceptability of subsonic transport aircraft. There is some remaining work aimed at maturing turboprop technology and transferring it to U.S. industry. Advanced concepts such as forward sweep for counterrotation are being explored.

Major elements of the subsonic transport program involve ducted prop/fan technology and high thermal efficiency cores. Emphasis is on noise reduction, with a goal of 6 to 7 EPNdB below FAR 36 Stage 3, to be achieved by fan source noise reduction and nacelle acoustic treatment. Through component/wind tunnel tests and aerodynamic/acoustic analytical modeling, a design methodology will be developed and then demonstrated in large scale. High thermal efficiency for an ultra-high-bypass engine core is achieved by increasing overall pressure ratio and turbine temperature in concert with improving turbomachine efficiencies and reducing/eliminating turbine cooling. In addition, novel concepts involving the use of offset cores, intercooling, and reheating are being studied for potential benefits.



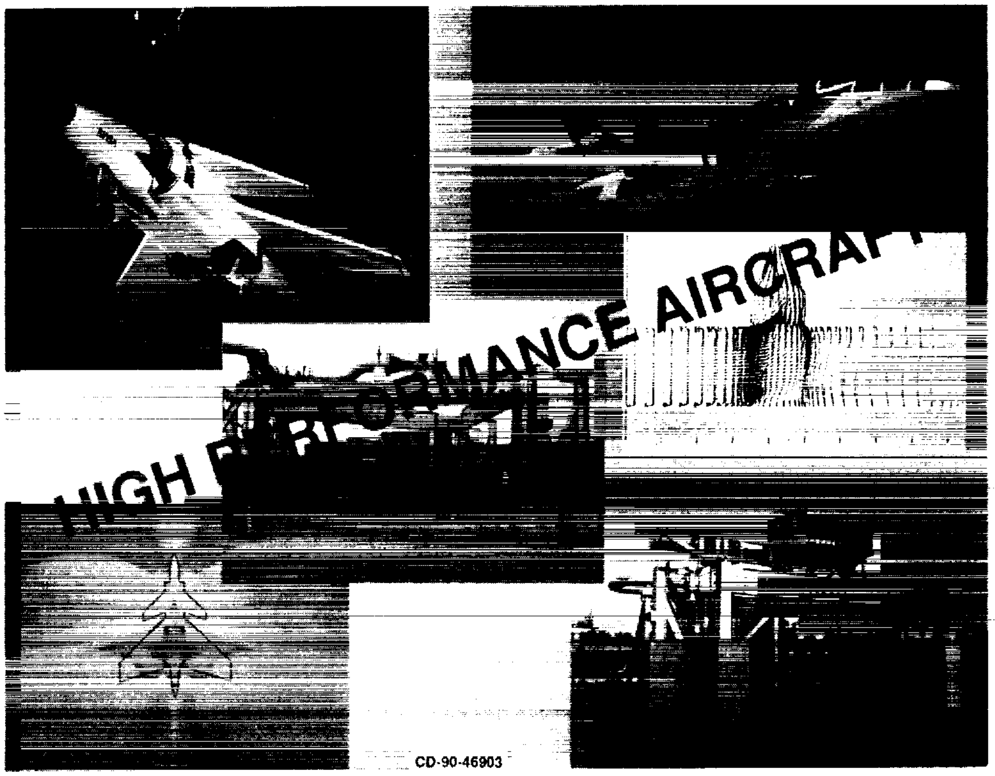
The goal of this program is to provide enabling propulsion technology for environmentally compatible and economically viable supersonic transports. In the near term, efforts are directed toward developing the technology base required for viable solutions to the environmental and economic barrier issues related to a proposed High-Speed Civil Transport (HSCT). Specifically, environmental programs are aimed at low emissions combustor technology that will result in no measurable impact on the ozone layer and low noise nozzle technology that will contribute to complying with FAR 36 Stage 3 noise rules. To address the economic issue, programs will develop and demonstrate the enabling materials and critical component technologies.

Far-term efforts will be directed at the development of advanced technologies for enhancing the performance of supersonic cruise propulsion systems. One example of such an effort is the development of supersonic throughflow fan technology to provide a basis for alternate propulsion system designs.



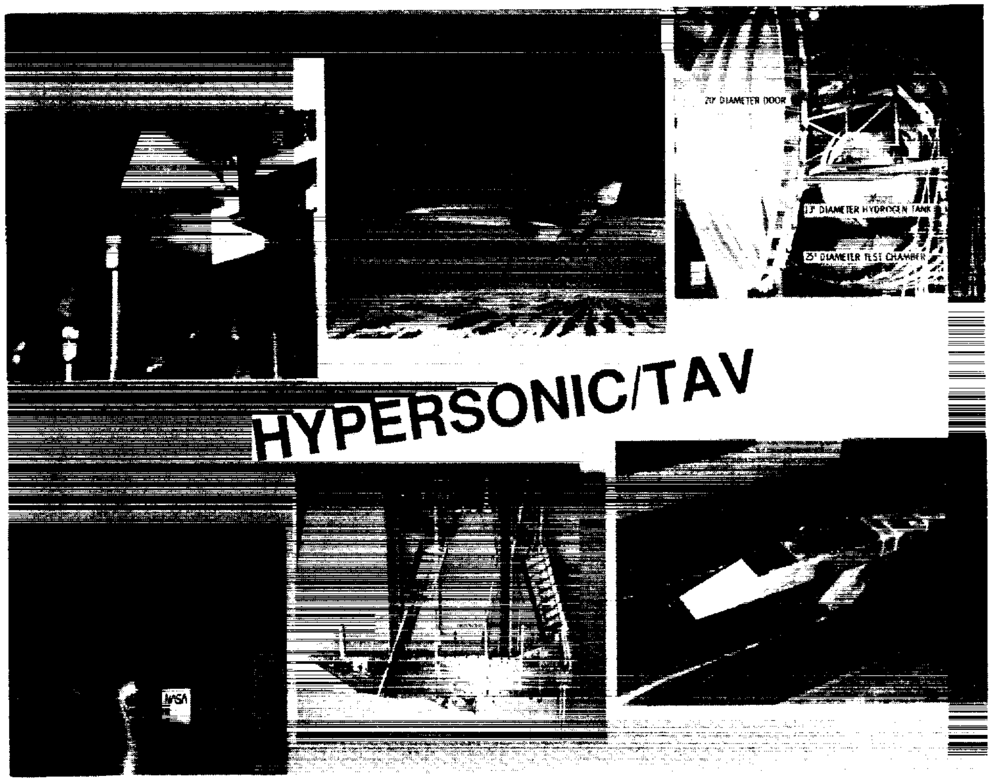
The goal of this focus is to provide innovative technologies to improve rotorcraft/ general aviation propulsion systems in order to strengthen the nation's competitive stance in the world market. A reduction of 30 percent in the fuel consumption of small engines is achievable through use of advanced cycles having higher temperature and pressure, improved turbomachinery components, and ceramic materials. Contributions to fuel savings, safety, and reliability can be made with advanced technology transmissions. Advanced anti-icing/deicing technology will contribute to aircraft safety.

In the area of small turbine engines, the research will address centrifugal compressors, combustors, and uncooled/cooled radial turbines. Detailed measurements will provide both an understanding of the flow physics and verification of predictive CFD capabilities. Combustion technology efforts will address very low pattern factors. Use of ceramic components to 2500 °F will be demonstrated. A rotary engine having low fuel consumption at high altitude is being explored. Advanced rotorcraft transmissions achieving 25 percent weight reduction, 10 dB noise reduction, and 5000 hr between removals will be demonstrated.



The goal of this program is to provide propulsion technology options for revolutionary performance capabilities in future high-performance military aircraft. Technologies and test facilities for future prototype vehicle programs will be developed. To minimize risk and assure success in flight demonstration programs, appropriate studies and ground-based tests will be performed to validate concepts prior to flight commitment. Participation in joint efforts with other NASA centers, the Department of Defense, and foreign governments are often key elements of these programs.

Primary emphasis is on propulsion systems for short takeoff/vertical landing (STOVL) and high maneuverability aircraft. Specifically, analytical assessment and experimental research will be conducted for unique components and problems such as internal valves and transport ducting, vertical thrusting and vectoring nozzles, hot gas ingestion, controls, and special thrust augmenters.



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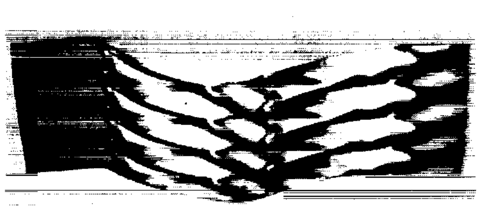
This focus has as its goal to provide enabling propulsion technology for future development of hypersonic/TAV flight vehicles. Accomplishment will be by developing specific hypersonic propulsion technologies, predictive codes, and an understanding of the governing physics that are needed to support the National Aerospace Plane (NASP) and other hypersonic vehicles.

Specific technologies to be addressed include hydrogen cooled engine components, hydrogen production, storage, and handling, inlet performance and operating characteristics, ramjet engine controls, and exhaust nozzle behavior including base burning. Verification of inlet, combustor, and nozzle CFD computer codes will give credence to predictive capabilities in the hypersonic regime.

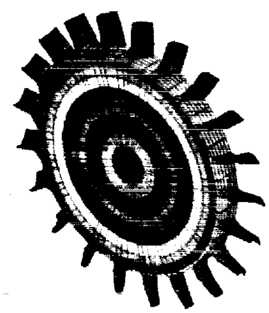
NASA Lewis is participating with the U.S. Air Force in the High Mach Turbine Engine (HiMaTE) program addressing propulsion at Mach 4 to 6. Studies, component demonstrations, and possible engine tests comprise this program.

Basic Discipline Technologies

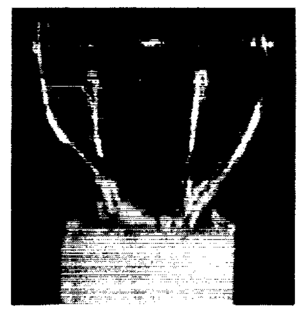


Internal fluid mechanics

Materials



Structures



Instrumentation and controls

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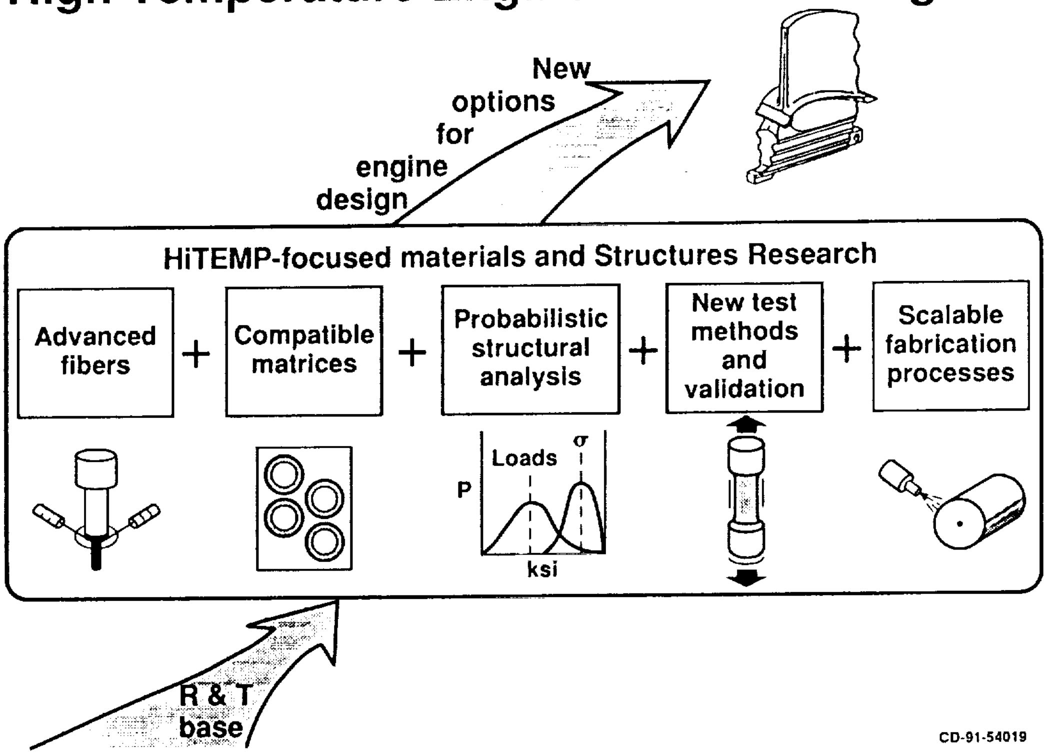
A key part of our strategy for the future is our commitment to build our in-house capabilities in the critical disciplines. This involves strengthening the basic discipline areas of materials, structures, internal fluid mechanics, and instrumentation and controls. Multidisciplinary programs, such as HITEMP and NPSS, are then used to help focus and integrate various disciplinary efforts on key aeropropulsion technology needs.

Advances in the basic disciplines are essential to achieving future advances in aeropropulsion technology. Internal fluid mechanics involves understanding and predicting the mass, momentum, and heat transport within the engine, thus enabling optimization of the aerodynamic design process. Engine materials have paced the progress of propulsion and will continue to do so for the foreseeable future - primarily as a result of increasing temperature capability. Sustained vibrations and large deflections in the engine can lead to loss of performance or of overall structural integrity, thus necessitating the understanding and prediction of structural behavior. Instrumentation technology is addressing both research and operational needs, which involve making measurements of increasing detail in environments of ever increasing severity. Key activities in the controls area involve the use of real-time intelligence to improve propulsion system performance and operability by closed-loop control.

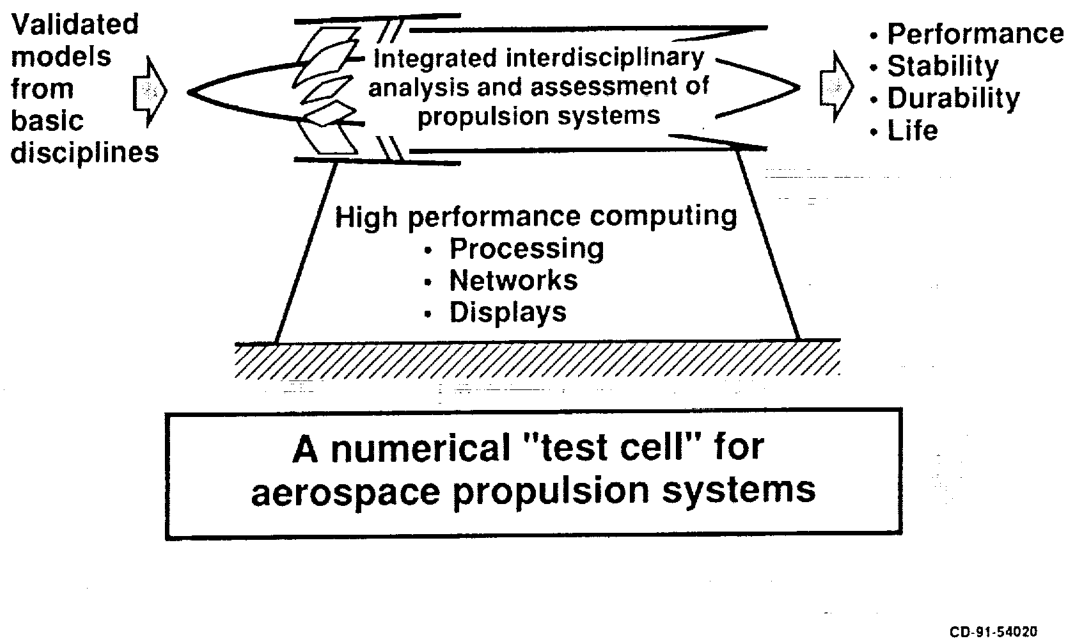
High Temperature Engine Materials Program



To achieve revolutionary advances in propulsion systems for 21st century transports, high temperature materials have been identified as the key technology to be addressed. NASA's High Temperature Engine Materials Technology Program (HITEMP) is directed towards generating this technology. The HITEMP Program is focusing primarily on lightweight composite materials to gain revolutionary advances in the operating temperature of advanced engines compared to the current state-of-the-art. Emphasis is being placed on polymer matrix composites (PMC's) for potential use in fans, casings, and engine control systems. Intermetallic/metal matrix composites (IMC's/MMC's) are under investigation for application in such areas as the compressor and turbine disks, blades, and vanes, and in the exhaust nozzle. For extremely high temperature applications, ceramic matrix composites (CMC's) are being explored for applications such as liners for the combustor and exhaust nozzle, turbine vanes, and ultimately the turbine blades and disks.

NASA considers this program to be a focused research effort that builds upon our basic research programs and that will feed results into application oriented projects such as the proposed NASA new initiative to develop the technology for a 21st century High Speed Civil Transport (HSCT). The Enabling Propulsion Materials (EPM) program is a major effort in the HSCT program and will utilize materials and structures concepts developed in HITEMP as well as elsewhere to provide the gains in engine materials that are required for economic viability and environmental acceptability. Also, HITEMP is closely coordinated with the joint DOD/NASA Integrated High Performance Turbine Engine Technology Program (IHPTET), and new materials from HITEMP may be utilized in future military applications.

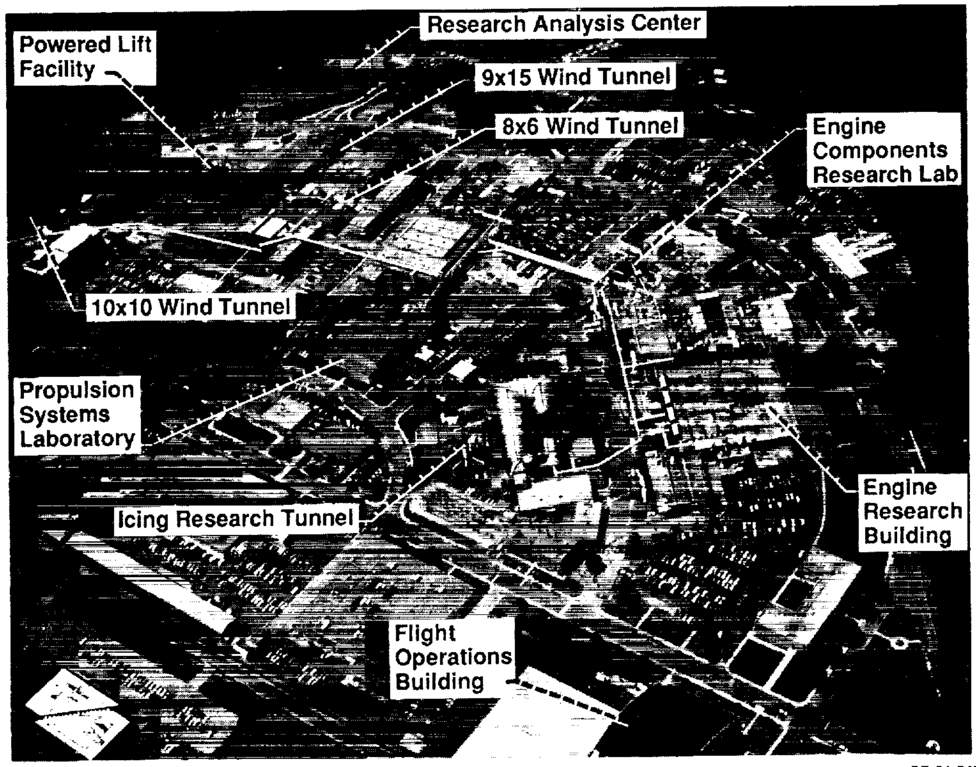
Numerical Propulsion System Simulation



The cost of implementing new technology in aerospace propulsion systems is becoming extremely expensive. One of the major contributors to the high cost is the need to perform many large scale system tests. Extensive testing is used to capture the complex interactions among the multiple disciplines and the multiple components inherent in complex systems. The objective of the Numerical Propulsion System Simulation (NPSS) is to provide insight into these complex interactions through computational simulations. This will allow for comprehensive evaluation of new concepts earlier in the design phase before a commitment to hardware is made. It will also allow for rapid assessment of field-related problems.

The NPSS approach means the coupling of disciplines and components computationally to determine system attributes such as performance, reliability, stability, and life. Since these system attributes have traditionally been obtained in the test cell, NPSS is referred to as the "numerical test cell". Such an integrated interdisciplinary system analysis requires advancements in the following technologies: (1) interdisiplinary analyses to couple the relevant disciplines such as aerodynamics, structures, heat transfer, chemistry, materials, controls; (2) integrated system analysis to couple subsystems, components, and subcomponents at an appropriate level of detail; (3) high performance computing platforms composed of a variety of architectures, including massively parallel processors, to provide the required computing speed and memory; and (4) user-friendly simulation environment.

Aeropropulsion Facilities



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Both experimental and computational facilities support our aeropropulsion research. Lewis wind tunnels offer a broad range of capabilities from near-static to supersonic. Unique capabilities at low speed are provided by the 9x15 and IRT. The continuous running 8x6 and 10x10 tunnels can test operating propulsion systems over a range of Mach numbers from 0.4 to 3.5. During the next several years, the Hypersonic Test Facility (Mach 5 to 7) at Plum Brook and a 21-in. Hypersonic Wind Tunnel (Mach 4 to 11), obtained from JPL, will be reactivated.

In the area of engine test cells, the Propulsion Systems Laboratory consists of two chambers capable of testing large-scale engines to Mach 3.5 and 70,000 ft conditions. A recent modification has enabled direct-connect testing at Mach 6 and 120,000 ft conditions with reduced mass flow. The Engine Components Research Laboratory provides for full-scale sea-level testing of turboshaft engines. Built primarily to support STOVL research, the Powered Lift Facility provides capabilities to test propulsive lift devices.

The Engine Research Building provides compressed air at various temperatures, pressures, and humidities as well as altitude exhaust and electrical power to some 60 test cells. A multiplicity of functions can be performed therein including fundamental research, instrumentation development, and component evaluation. Computational facilities at Lewis include a class 7 supercomputer, satellite access to the National Aerodynamic Simulator (NAS) at NASA Ames, top-level scientific workstations, and local-area networks. And finally, although we are not a flight research center, Lewis does have aircraft that are used to augment ground-based testing.

CONCLUDING REMARKS

The past half century at NACA/NASA Lewis has been one of great accomplishment for aeropropulsion technology. From fixing the B-29 engine problems to validating the advanced turboprop, we have contributed to expanding the aeropropulsion operating envelope while improving fuel efficiency, environmental acceptability, and flight safety. The award of the Collier Trophy, the most coveted award in the aerospace field, suggests that our strategy of emphasizing high-payoff high-risk innovative aeropropulsion research and working closely with our industrial and academic partners is having success.

We certainly remain bullish on the future for aeropropulsion research at Lewis. Improvements in propulsion technology historically have provided a major share of aircraft performance improvements, and propulsion advances will be even more critical to the development of future aircraft. So we plan to continue to play a strong leadership role in advancing technology for future aircraft engines. More details of our current and planned efforts are described in the following sessions of this conference.

In summary, we are committed to maintaining a leading-edge research program, a talented staff, and world-class facilities in order to challenge the future and provide the technology advancements for 21st century aeropropulsion.